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Optimizing the Long-term Retention of Skills: Structural and Analytic Approaches to Skill Maintenance III

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University of Colorado

for

Contracting Officer's Representative
Judith Orasanu

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This research program identifies the characteristics of knowledge and skill most esistant to decay because of disuse. The program is divided into analytic and structural pproaches. Two lines of research are used to investigate skill retention and maintenance sing the analytic approach. The first investigates different laboratory analogues of omponent military skills, and the second investigates parallel natural skills learned by he college population during prior education. We have developed five laboratory method- logies and completed experimental studies involving each of them, and have identified four atural skills and gathered long-term retention data for each of these skills. For the tructural approach, we designed an experimental paradigm to assess the detailed encoding f new knowledge at presentation and at delay using verbal report techniques and chronometric easurement of retrieval components. We completed several studies of retention of vocabu- ary items with this paradigm. In addition, we formulated a theoretical framework, on the

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19. ABSTRACT (Continued)

notion of procedural reinstatement, and have used this framework to account for findings from many different facets of our research program, both analytic and structural.

Executive Summary of Progress: August 11, 1988 to August 10, 1989
Optimizing the Long-term Retention of Skills:
Structural and Analytic Approaches to Skill Maintenance III
Alice F. Healy, K. Anders Ericsson, and Lyle E. Bourne, Jr.

This research program seeks to identify the characteristics of knowledge and skill which are most resistant to decay due to disuse. Our research can be divided into two complementary parts. The first part is concerned with experimental analysis of factors influencing and improving retention of skill components. The second part is concerned with analysis and assessment of the structure of acquired memory and skills and how to monitor differential retention of components. The eventual goal of both parts is to be able to make relevant recommendations about training routines for long-term skill maintenance.

A new line of investigation, involving both the analytic and structural approaches, began consequent to the arrival of three Army tank simulators. This effort is concerned with the study of complex military skills. A study was completed involving the extensive training of two subjects with the simulators.

The analytic approach. We have developed two lines of research for investigating skill retention and maintenance using the analytic approach. The first line of research involves investigating different laboratory analogues of component skills of electronic technicians. The second complementary line of research involves investigating parallel natural skills learned by the college population during their prior education.

We have developed five laboratory methodologies, and we have completed investigations for each of them. The laboratory tasks involve (a) target detection, (b) data entry, (c) learning logical rules involved in circuit design, (d) memory for numerical calculations, and (e) temporal, spatial, and item components of memory for lists. We have also identified the following four natural skills and have completed investigations for each of them: (a) mental multiplication, (b) algebra, (c) data entry, and (d) temporal, spatial, and item components of memory for class schedules.

The structural approach. We have designed an experimental paradigm which allows us to assess the detailed encoding of new knowledge at presentation and at delay using verbal report techniques and chronometric measurement of retrieval components. Several studies of retention of vocabulary items have been completed, in which subjects have been instructed to use the keyword method with supplied keywords.

Overview of findings. One of our initial aims in this research was to validate the concept of "permastore" initially proposed by Bahrick to account for his finding that some information remains permanently intact in memory. Indeed, in a number of our lines of investigation (e.g., target detection, mental multiplication, and data entry), we have found evidence for a surprising degree of long-term skill retention. We have formulated a theoretical framework, focusing on the importance of procedural reinstatement, and this framework enables us to understand this impressive memory performance. In contrast, in other studies we have conducted (e.g., memory for numerical calculations, vocabulary learning, and components of memory for class schedules), we found considerable forgetting over even relatively short retention intervals. We have been able to place these studies in the same

general theoretical framework developed to account for permastore, and we have been able to derive from these studies indications of the specific factors which facilitate retention.

Annual Interim Report for the period August 11, 1988 to August 10, 1989
Optimizing the Long-term Retention of Skills:
Structural and Analytic Approaches to Skill Maintenance III

A. Accomplishments

Proposal. At the beginning of this year, we prepared our contract renewal proposal, which we submitted on October 28, 1988. This proposal includes 29 experimental studies, 9 of which are specified in detail. Nine of the 29 experiments mentioned and 5 of the 9 experiments described in detail involve the TopGun simulator. The development of these experiments required that we master the programming and operation of this simulator. We also completed a preliminary experiment with the simulator. This experiment involved extensive training of two subjects for twelve acquisition sessions. A retention test followed three months after the end of acquisition.

We recently submitted an Addendum to our contract renewal proposal. In this Addendum we relate our proposal to the theoretical framework we subsequently developed and discussed at the ARI contractors' meeting in Ft. Gordon, Georgia (see below). We also proposed two new experiments that would provide direct tests of our theoretical framework and extend its generalizability.

Meetings and visits. In September, Dr. Walter Schneider, a fellow ARI contractor from the University of Pittsburgh, visited our campus and our laboratory. Both as a group and individually the members of our project discussed with him our research efforts and learned about his related efforts. Dr. Schneider provided some very helpful and stimulating feedback to us.

In September, Bourne visited the University of Wisconsin and discussed our research on data entry at a symposium there.

In November, eight of us (Healy, Bourne, Ericsson, Fendrich, Crutcher, Messamer, Frick, and Tetewsky) went to the annual meeting of the Psychonomic Society in Chicago, Illinois. We discussed our research with colleagues both informally and in two formal presentations.

Three of us (Healy, Ericsson, and Bourne) attended the annual contractors' meeting on Skill Acquisition and Retention at Ft. Gordon, Georgia on February 27 - March 1. We presented a report at that meeting which summarized some of our recent experimental findings and placed them into a general theoretical framework which allowed us to account for both the impressive memory performance we have observed in the target detection, mental multiplication, and data entry tasks as well as the considerable forgetting we have observed in our studies of memory for numerical calculations, vocabulary learning, and components of memory for course schedules. We also included in the presentation a discussion of our initial work with the TopGun simulator and some of the research we have planned with the simulator.

At the meeting in Georgia, we met Dr. Robert Wisher, an ARI researcher who introduced us to an intriguing problem of individual differences involving the training of receivers of Morse Code. We discussed this problem with him, he subsequently sent us some relevant material, and we initiated plans to investigate possible ways of solving this problem both in our laboratory and in collaboration with Dr. Wisher at the training site itself. One of the two new

studies in our addendum involves the task of Morse Code. This study investigates the long-term retention of that task but may have interesting implications concerning the problem of individual differences.

In August, two of us (Healy and Bourne) attended the annual meeting of the American Psychological Association. Healy presented an invited address entitled "The long-term retention of skills." This address summarized the work on our project.

Technical reports. At the beginning of this year, we performed the final revisions on two technical reports summarizing our work in this project during its initial stages when it was supported by the Air Force Human Resources Laboratory, before support was provided by the ARI.

TopGun simulators. We completed two sets of analyses of our preliminary experiment with the TopGun Simulators. This experiment involved extensive training of two subjects followed by a long-term retention test one-month at the end of acquisition. The initial analyses employed a number of different indices of performance. According to all of the indices, there was substantial improvement in the skill across the acquisition sessions. According to some but not all of these indices, there was significant forgetting across the retention interval, but even in those cases performance at the retention test was superior to that exhibited at the beginnning of acquisition.

The aim of the second set of analyses was to isolate the various processing components of the tank gunnery skill. Indeed, we were able to distinguish between some components which showed forgetting across the three-month retention interval and other components which showed no forgetting. However, these analyses can only be seen as suggestive, because of the small number of subjects employed so far in this experiment.

The Analytic Approach

We have made further progress in our testing of both the laboratory skills and the natural skills which we began in the first two years.

Laboratory Skills

Target detection. After a delay of approximately six months, we retested our third and fourth subjects given extensive training in target detection. These subjects were trained by means of a varied mapping procedure, instead of the consistent mapping procedure used with our first two subjects. One of these new subjects showed very little learning during training, so that his retention data are of minimal interest. The other subject, however, did show considerable improvements during acquisition, so that it is of interest to determine how much forgetting she demonstrated over the long retention interval. We found very little forgetting, an amount roughly comparable to that of the first two subjects. Because this new subject was exposed to varied mapping training whereas our first two subjects were exposed to consistent mapping training, two interesting tentative conclusions can be drawn. First, consistency of training does not seem to be necessary for entry into permastore. Second, automaticity does not seem to be associated with entry into permastore. This latter conclusion follows from the fact that previous researchers, including Shiffrin and Schneider (1977), found no evidence of automaticity with varied mapping

training.

We also completed for a fifth subject the initial acquisition phase of extensive training on the target detection skill with the varied mapping procedure. Preliminary data analysis revealed that this subject also showed improved performance both in terms of response latencies and accuracy across the twelve sessions of training. Further, a decrease in the frame size effect indicated that this subject became more automatic as training progressed. This subject will be retested next year in order to determine how well this target-detection skill is retained.

In collaboration with Janet Proctor, we conducted a new experiment which followed our observation that the word frequency disadvantage (the tendency to miss target letters in common as opposed to rare words) was diminished with previous practice at detecting letters in prose. For this new experiment we constructed a prose passage which we could use in three different letter detection tasks, one involving the letter n and the common word and, the second involving the letter t and the common word the, and the third involving the letter h and the common word the. Subjects read this passage followed by a test passage involving the letter h and the common word the. We found that only practice with the same target letter yielded the reduction of the word frequency disadvantage. Practice with the same passage, even with the same common test word, was not sufficient if the subject did not have the same target letter. These findings were both clear-cut and surprising.

With Janet Proctor we later completed a second follow-up experiment investigating the loss of the word frequency disadvantage after practice performing a prose letter detection task. This experiment included important controls missing from the previous studies. The preliminary analyses of this experiment have recently been completed. They indicate that there is transfer from one prose letter-detection task to a second task involving a different target letter if and only if that letter also occurs in the same frequent test word and is processed more rapidly than the initial target letter. In particular, practice detecting the letter h, which occurs in the medial position of the word the, transfers to detecting the letter t, which occurs in the initial position of the word the, but does not transfer to detecting the letter n, which occurs in the medial position of the word and. Also, practice detecting the letters n or t does not transfer to detecting the letter h. These findings can be understood by considering that the letter t is probably detected before the letter h in the word the, and these results are consistent with our previous experiments, which had also indicated differences between the detection of the letters t and h.

On the basis of encouragement and suggestions by the journal editor and reviewers, we (Healy, Fendrich, and Proctor) completed three revisions of our manuscript reporting our initial studies of target detection; this manuscript is now in press in the Journal of Experimental Psychology: Learning, Memory, and Cognition. Our revision includes our new theoretical analysis of the factors influencing the degree of long-term retention. This analysis emphasizes the importance of procedural memory in enhancing skill retention.

Data entry. We prepared a talk summarizing three of our studies in our series of experiments on data entry. An early version of the talk was presented in September by Bourne at the University of Wisconsin. A subsequent version of

the talk (by Fendrich, Healy, and Bourne) was presented at the annual November meeting of the Psychonomic Society in Chicago.

David Fendrich completed his doctoral dissertation, which is a report of three of our expreriments on data entry. The dissertation also includes an extensive review of the literature on implicit memory. This dissertation was extremely well received by the examining committee, David Fendrich successfully passed his final oral examination, and his final version of the dissertation was approved by his committee and accepted by the Graduate School.

We also completed the analyses and initial write-up of a new data entry experiment. This study provided the basis for an undergraduate honors thesis by Antoinette Gesi, who graduated this winter Magna Cum Laude. We (Gesi, Fendrich, Healy, and Bourne) also presented a paper describing this work at the joint annual meeting of the Rocky Mountain Psychological Association and the Western Psychological Association on April 27, 1989.

Memory for numerical calculations. Our manuscript on this topic was accepted for publication with revisions suggested. We completed the recommended revisions and proofreading and the article is now in print in the Journal of Experimental Psychology: Learning, Memory, and Cognition.

Learning logical rules involved in circuit design. We completed the initial analyses of our follow-up study on this topic. Although the preliminary results are very promising, the initial analysis revealed that some subjects needed to be replaced because they did not successfully learn the rules in the time allotted. We finished testing the additional subjects needed but we have not yet completed the data analyses.

Temporal, spatial, and item components of memory for lists. In our contract renewal proposal we outlined a new series of experiments on this topic. We completed conducting two preliminary experiments in this series. These experiments compare memory for size order with memory for temporal and spatial order information. This work provided the basis for the first-year research project of USAF Captain Michael Scheall, who presented a summary of this study at the Department of Psychology Annual Miniconvention on May 1, 1989.

We also initiated the design of two new experiments that link our previous work on the learning and long-term retention of temporal, spatial, and item information with our previous work on data entry. These experiments should provide information concerning both the learning of a data entry skill when based on processing either temporal, spatial, or item information and the relative importance of the cognitive and the motor aspects of the long-term retention of data entry skills with respect to temporal, spatial, and item information.

Natural Skills

Mental multiplication. We retested both of the subjects given long-term

training in the multiplication skill, the first after a 7-month and then a 14-month retention interval (she had been retested initially after a 3-month interval) and the second after a 4-month and then a 7-month interval. At these tests both subjects showed very little loss of either speed or accuracy on this task, despite the fact that they had shown substantial gains in performance during the 12 acquisition sessions. Although retention was high in each case, some forgetting was evident. Recently, the first subject was retested again after an interval of approximately 20 months. At this retesting the original motor response was employed; at all of the previous retests an oral response was used instead. Forgetting was evident at this final retesting, but performance was still considerably better than at the start of training. Specifically, the response latencies at this retesting were comparable to those during the sixth training session.

We completed conducting a group experiment to assess the long-term retention of the improvements in multiplication performance learned in the laboratory. This experiment allowed us to assess whether subjects represent the two versions of a problem (e.g., 2 X 3 and 3 X 2) separately in memory or as a single entry. Our intial analyses revealed that the two versions of a problem are indeed stored separately, because subjects responded more rapidly and more accurately to the versions that they studied ("old" problems) during the acquisition session one-month previously than to the versions seen only at test ("new" problems). The one exception to this finding occurred with the problems involving the digit 1 (e.g., 1 X 3), which according to previous research do not rely on memory storage but rather the use of a simple rule. The finding for the problems involving 1 seems to rule out enhanced perceptual processing of the stimulus as the locus of the old-new difference. Rather, it seems that the association between the stimulus problem and the answer has been strengthened in memory. In any event, subjects showed no explicit recognition memory for the old problems, although the recognition memory test was given at the conclusion of the experiment, after the testing (which included both old and new problems) was completed.

We recently completed a second group experiment assessing the long-term retention of the improvements in multiplication performance learned in the laboratory. In this new study, subjects were trained on a subset of the problems comprising the 1-9 multiplication table. This experiment allowed us to assess the degree of transfer between related multiplication problems. For example, subjects were trained on 4 X 3 but not 3 X 4, 6 X 2, or 2 X 6; in a final retention test performance on all four problems was compared. A formal recognition procedure was also included in this experiment for some subjects at the beginning of the retention test and for other subjects at the end of the retention test. The initial analyses of this experiment revealed retention of the old problem reflected both in terms of improved response latencies relative to new problems and in terms of explicit recognition ratings. There was also significant transfer in terms of both of these measures to the reverse problems, which were the same as the old problems except for the order of the operands. This finding held even for those sets of problems which shared the same answer, as in the example above, so that the advantage for the reverse problems relative to other new problems could not be attributed simply to the fact that the reverse and old problems shared the same response. In agreement with the earlier study, subjects were not able to discriminate the old from the reverse problems on the explicit recognition test given at the end of the retention session, although such discrimination was evident on the recognition test given at the beginning of the retention session.

We (Fendrich, Healy, and Bourne) have submitted an abstract for a poster summarizing the two group experiments on mental multiplication for presentation at the next annual meeting of the Psychonomic Society.

Algebra skills. We (Meiskey, Healy, and Bourne) completed our invited report for the University of Colorado journal On Teaching. This article is now in press and scheduled to appear in print this Fall.

Temporal, spatial, and item components of memory for course schedules. We completed the analyses of our second experiment on memory for course schedules, and we completed the second retesting of subjects in our first experiment. This study of memory for course schedules provided the basis for the doctoral dissertation of USAF Major William Wittman. The dissertation was completed and accepted with much praise by the committee and the graduate school this June.

Results of our first experiment demonstrated the superior retention of the spatial component over the temporal or item components in memory for naturally learned course schedules. Spatial component recall showed a clear advantage for all three test sessions, with retention intervals ranging from 12 to 36 months. This long-term advantage for spatial information is consistent with the short-term advantage for spatial information we have found the laboratory.

Our second experiment involving memory for course schedules confirmed this spatial component superiority. In this experiment, we sought to determine what degree proceeding to and from classes contributed to the spatial advantage. Subjects were therefore instructed to learn an actual class schedule, but were never given the opportunity to physically practice their schedule, that is, to walk from building to building. Results again showed a spatial component advantage. Additionally subjects were asked both to locate their classes on a campus map and to provide the names of class locations. In the naming of class locations, subjects did not show an advantage for this information over the temporal or item components, thus suggesting a truly spatial memory interpretation of results.

Both experiments provide support for the general theoretical framework we have applied in our other experiments. That is, memory performance can be explained in terms of the degree to which the demands of the memory test allow reinstatement of procedures acquired in training. Such procedures may be both motoric (as in walking to a class) and cognitive (as acquired in studying the campus map).

Data entry. We retested our single subject who had extensive practice with the data entry skill. This retesting took place after a 21-month retention interval. Although significant forgetting was found, most impressive was the extremely high degree of performance which was maintained across the lengthy retention interval.

The Structural Approach

We conducted a number of studies to extend our previous investigations of the acquisition and retention of Spanish-English vocabulary items.

Specifically, we completed a study to assess the effect of extended practice on retrieval of the English equivalents of Spanish words. Our primary goal was to determine whether a direct association is formed between the Spanish word and the English equivalent as a result of extended practice. The initial results suggest that subjects are indeed able to retrieve directly the English equivalent from the Spanish word.

We also designed the materials for a new experiment to examine how preexisting knowledge can be used initially to acquire and later to reaccess Spanish vocabulary items.

In addition, we recalled four subjects from our original vocabulary retention study and retested them after a one-year delay. Retention of the English equivalents declined considerably: from 80% (one week or one month delay) to less than 15% (after one year). However, retention results for the two subtasks, the Keyword Retrieval Task (Spanish-Keyword) and the English Retrieval Task (Keyword-English), were strikingly disparate. Performance on the English Retrieval Task was similar to the Full Retrieval Task: less than 15% recall. However, performance on the Keyword Retrieval Task was 80% correct, almost no loss at all. These results, consistent with our earlier ones, suggest that failure to recall the English equivalents is due to difficulty in recalling the interactive image. The keyword component, on the other hand, shows remarkably good retention, even after a delay of a year.

Finally, we completed a keyword generation experiment, in which we asked subjects to generate keywords for the Spanish words used in the retention experiments. Between 40% and 60% of the time, subjects in the generation experiment generated the same keywords as we had used in the retention experiment. Comparing these numbers to the 80% recall after a year suggests that the remarkable retention for keywords is in part due to inference processes. Subjects either guess the keyword in some cases or are able to generate likely keyword candidates and then check the memory trace. Further, we completed running a second group of subjects in the keyword generation experiment. These data have been tabulated but have not yet been analyzed.